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GENERAL REQUIREMENTS FOR A BROADBAND PERFORMANCE MODEL

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ADMINISTRATIVE INFORMATION

This technical memorandum was prepared under job order no. 795P40, NUWC Bid and Proposal for 1995. The principal investigator is Mr. E. Smith (code 3121).

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INTRODUCTION

Recently, new emphasis has been placed on the development of active broadband sonar systems as a means of improving the detection and prosecution of small stealthy submarines particularly in littoral environments. As the interest in broadband sonar systems continues to expand the need for a versatile broadband performance prediction model with which to evaluate the effectiveness of these systems becomes increasingly urgent. In response to NUWC's recognition of this growing need, a broadband version of the Generic Sonar Model (GSM version G) was developed by the author that ultimately computes broadband system performance in the form of signal excess tables. While this application has proven to be useful in many situations, some of the limitations inherent to GSM (such as range independence and flat water bottoms) restricts its usefulness in certain situations.

It is the intent of this document to investigate in very general terms the environmental and system parameters as well as the "frequency sensitive" computational requirements that must be met in order to construct a new and more multifaceted broadband performance model utilizing the same basic approach found in the broadband version of GSM. Ideally development of a new broadband model would dispense with at least some of the limitations found in the current version of GSM and perhaps improve some other features such as parameter checking and error messages. This document will not deal with the development of a particular model per se but will discuss the "frequency dependent" issues that must be considered when constructing a broadband model that uses the same philosophy and general constructs as the broadband GSM.

Broadband modeling raises many new questions regarding the validity and computational methodology of many of the environmental and system parameters that have traditionally been input to narrowband models. This topic is a large and important area of concern, but is a separate area of investigation that is outside the scope of this paper. For the sake of expediency, it will be assumed that valid inputs are available to the user for all environmental and system parameters and our discussion will be focused on the proper usage of this data within the model to achieve the desired results.

THE BROADBAND STRATEGY

In the past, GSM has long been considered a versatile but primarily narrowband acoustic research model (Ref. 1). Originally it was designed to perform passive performance predictions but has long since been enhanced to include active modeling as well. Recently it has undergone further modification which has furnished it with the capability to perform broadband signal excess predictions. It achieves this by reworking and combining the yield from numerous narrowband model computations into a broadband result (see figure 1).

Essentially the user divides or "digitizes" the complete broadband source pulse into a series of shorter narrowband source pulses that are incremented in frequency from one another such that if summed together their individual bandwidths and pulse lengths would equal the original broadband signal. For instance, if a user wished to model a linear FM source pulse that was 2.0 seconds long and 500 Hz to 2000 Hz in bandwidth, he might input to the model ten 0.2 second source pulses each 150 Hz in bandwidth. To actually do this in broadband GSM the user would specify a pulse length of 0.2 seconds and a frequency minimum of 575 Hz, frequency maximum of 1925 Hz and a frequency increment of 150 Hz.

The remaining "environmental parameters" should be entered as they pertain to the fractional pulse length and bandwidth of the segmented subpulses. The user then directs the model to compute transmission loss and reverberation levels for each narrowband source segment. Fortunately, GSM in its original state possessed some form of frequency sensitive input and computation for nearly all of the environmental models and parameters necessary to compute transmission loss and reverberation. This helped to greatly reduce the amount of new software development needed to adapt GSM to broadband modeling outside of the signal excess subroutine itself.

Once transmission loss and reverberation levels are computed, the broadband signal excess subroutine combines the narrowband components of signal strength and reverberation with the frequency dependent "system parameters" in such a way as to compute broadband signal excess. It does this by separately summing the magnitudes of reverberation and ambient noise and finding the average of the received "signal strengths" for all subpulse segments. Frequency sensitive system parameters such as target strength and directivity index must be handled carefully to be sure that they are properly incorporated into these totals.

At present the broadband signal excess subroutine requires that a source pulse be divided into subpulses that consist of equal pulse lengths and bandwidths. It is conceivable that this may unnecessarily constrain the users ability to accurately portray the characteristics of a desired source pulse. However, subpulses of varying pulse length and bandwidths could be successfully handled by the model (if a means of inputting them were available) by installing "time weighted" averaging of signal strengths and "bandwidth weighted" Doppler shifting of each subpulse in the signal excess subroutine. This would allow the user nearly complete freedom when deciding how to divide the source pulse into subpulse segments.

MODEL CONSIDERATIONS

If a new broadband performance prediction model is to be developed that dispels the "range independent" limitations of GSM, then it must be capable of successfully integrating "range dependent" environmental parameters with the three basic functions necessary to compute signal excess. Ideally the model would perform the difficult task of

combining variable water bottom geometry and distributed sound velocity functions with frequency sensitive "environmental parameters" to compute transmission loss and reverberation. Additionally, it must also be able to compute broadband signal excess utilizing "system parameters" that are either frequency sensitive or bandwidth sensitive (or both).

In order to successfully perform these functions, careful consideration must be given to the ramifications of range dependency and frequency sensitivity with regard to all the parameters, environmental models and algorithms that will be called into use during the computation of broadband signal excess. While the details of how these functions are actually implemented in the broadband model can only be decided during software development, we can examine in at least a cursory sense the form in which these parameters might best be input to the model in order to provide users with the greatest ease and flexibility of use.

If as stated earlier we adopt a strategy of broadband modeling similar to that used in GSM, then inputting the segmented broadband source pulse is the user's first and perhaps foremost concern. GSM has the ability to accept linearly incremented broadband source pulses by specifying a starting frequency, ending frequency and frequency increment. This is a convenient method of entering linear FM source pulses where pulse length and bandwidth are held constant across all subpulses. Source level can be controlled in the individual subpulses by entering a separate source level versus frequency table. This useful form of entering linear FM source pulses should probably be maintained in future broadband models.

In order to model broadband source pulses more exotic than those that exhibit linear variation in frequency, a more flexible method of inputting subpulse attributes is needed. One method that would provide users with greater flexibility when attempting to subdivide a broadband source pulse is to enter the defining characteristics of each subpulse as the elements of a table. The table might contain one row or column of subpulse attributes for each frequency segment. At a minimum these characteristics would have to include the subpulse center frequency, bandwidth, pulse length and source level. Ideally, each parameter could be entered completely independent of any other. This would allow the user to segment a broadband source pulse into subpulses of various pulse lengths or bandwidths and separate them by irregular increments in frequency. With this methodology, the user should be capable of entering whatever combination of parameters necessary to satisfactorily describe the defining characteristics of virtually any broadband source pulse.

If the ability to input non-uniformly segmented subpulses is added to the broadband model, then it will be necessary to perform at least a couple of adaptations to the current broadband signal excess subroutine. To accommodate subpulses of unequal pulse length, the signal strength averaging algorithm must be converted from a straight summation averager to a "pulse length weighted" signal strength averaging mechanism. This modification can be accomplished by scaling each subpulse's signal strength by the

"subband pulse length / total broadband pulse length" weighting factor and then summing weighted signal strengths. This will ensure that subpulses that comprise relatively larger proportions of the total broadband source pulse have a correspondingly greater influence on the resulting average signal strength that is used in the signal excess equation.

A similar adaptation must be made in the signal excess subroutine to accommodate the use of subpulses of varying bandwidth. When a single undivided source pulse is used in the model, the amount of reverberation appearing in the receiver band is determined from the amount of overlap that occurs between the unshifted reverberation frequency band and the Doppler shifted signal band, assuming of course, that either source, receiver or target has some relative component of motion. When a segmented source pulse is entered into the model the proper amount of frequency band overlap can only be attained by redistributing the total broadband Doppler shift to each of the subbands in an amount relative to the proportion each subband constitutes of the entire source pulse. This can be accomplished by applying a "bandwidth weighting factor" to each subband when computing the individual Doppler shifts which will properly reapportion the amount of reverberation and signal frequency band overlap occurring in each subpulse. Perhaps the easiest way to perform the bandwidth weighting in the signal excess subroutine is to multiply the summed components of velocity by the "subband bandwidth / broadband bandwidth" weighting factor and use this proportional velocity to compute each subband's Doppler shift. Ultimately, the proportioned Doppler shifts will produce reverberation and signal strength overlap in each subband such that when summed will equal the amount of overlap that would occur in the undivided broadband source pulse.

Once the frequency bands into which the source pulse will be subdivided have been decided, the user is ready to begin signal excess modeling by computing broadband transmission loss and reverberation. However, before these can be ascertained, the user must supply the model with several "environmental parameters" which are necessary to complete this computation. Some of these parameters, such as reflection coefficients, scattering strengths and volume attenuation, are "frequency sensitive" inputs and others, such as sound speed velocities and bottom bathymetry, are "range dependent" inputs. Experience has shown that whenever designing inputs to a model, it is advisable to allow as much flexibility as possible as to the forms in which those inputs can be made.

Normally GSM provides the user with two and sometimes three alternatives for inputting the "frequency sensitive" parameters to the model. The user always has the option to enter frequency sensitive parameters in the form of a table which contains environmental parameters indexed by frequency (and possibly referenced by other variables as well). The table can be inserted directly into the GSM runstream or it can be read into the model from a file that is named in the runstream. Users also have the option, in most cases, of choosing from a number of environmental submodels that are embedded within GSM's source code. These self contained modules compute environmental parameters on an as needed basis using frequency dependent equations. Lastly, in some instances the user can enter the name of an environmental library file which GSM accesses in order to interpolate parameter values from the appropriate precomputed environmental tables. It is the authors

opinion that all of these input methodologies should be retained and perhaps expanded upon in the future in the development of a new broadband model.

The second category of environmental parameters that the model needs in order to compute reverberation and transmission loss are known as "range dependent" parameters. The term "range dependent" signifies that while these parameters may vary greatly in value over range, they are relatively insensitive to changes in frequency. In general, there are two of these parameters, one deals with the physical shape of the water bottom interface (bathymetric profile) and the second concerns the distribution of sound velocity profiles throughout the ocean. While the manner in which these parameters are input to the model can be done without regard to frequency, it must be done with respect to spatial coordinates that define both the structure of the ocean sound velocity field and the shape of the water bottom interface. Most often the input of these parameters is fairly straight forward employing some variation of a Cartesian coordinate system in which sound velocity profiles and bathymetric depth points are assigned to various reference points within a grid. It is the implementation and integration of these spatial parameters within the propagation and reverberation models that is no simple matter. Fortunately, for both the reader and author, no solution to that problem need be offered here.

Once the necessary environmental parameters have been entered into the model, transmission loss and reverberation tables may be generated for each of the subpulses using the "frequency" and "range" sensitive subroutines contained in the model. When complete all that remains is to input the necessary broadband "system parameters" and then compute the signal excess performance predictions. Unfortunately, it is not quite as simple as it seems, however, since the strategy adopted in GSM requires the user to enter "segmented" broadband system inputs for some parameters and "unsegmented" system inputs for others. This situation requires particular attention to detail by the user and special consideration and handling of parameters within the model.

The "segmented" frequency sensitive system parameters normally required by broadband GSM include the four parameters mentioned earlier that define the subdivided broadband source pulses (center frequency, bandwidth, pulse length, source level) as well as target strength, ambient noise, self noise and directivity index (array gain). All segmented system parameters must have their values determined as they pertain to the characteristics of each fractional subpulse. The general form of input for these entries are parameter versus frequency index tables (described earlier) or employment of an embedded submodel whose frequency dependent algorithms are contained in the model's source code. In the future it might be advantageous to consider entering all eight of the aforementioned segmented system parameters into the model by placing them into a single large array.

There is one other segmented frequency sensitive system parameter that, unlike those just discussed, is generally ill suited for input to the model in the form of a table. Frequency sensitive source and receiver three-dimensional beampatterns are usually too large to be easily or efficiently entered into the broadband model from an external source. To be complete, each file must contain beampattern magnitudes indexed by horizontal bearing,

vertical D/E angles and subpulse frequencies. In some cases the size of the tables can be reduced at the expense of beampattern accuracy by holding the beampattern constant either vertically or horizontally or by only inputting information about the MRA (main response axis). However if the number of frequency subbands is more than a few then even these reduced tables become quite large and unwieldy.

A much simpler and more efficient method of incorporating beampatterns into a broadband model was devised for the latest version of GSM. Instead of entering large tables of beampattern magnitudes, only the physical and operational characteristics of the source and receiver elemental arrays need to be installed in the model. Included among the essential array attributes are the X, Y, Z spatial coordinate of each element, the weighting and phase delay of each element (if any) and the steering direction of the MRA. All of these array parameters are normally "insensitive" to frequency meaning that the same array parameters can be used for all frequency subbands in the model. This alone will normally reduce the size of the input tables by at least an order of magnitude.

Once entered into the model these element arrays are accessed by a submodel known as GBEAM (Ref. 2) to compute three-dimensional beampattern tables, one for each of the subpulse frequency bands in the broadband model. These tables remain internal to the model and are utilized by the signal excess subroutine to compute both broadband reverberation and signal strength. This method eliminates the need for the user to take the additional step of creating beampattern tables externally and removes the inefficiencies generally associated with reading large external files into the model.

In addition to the parameters described above, there are three "unsegmented" frequency sensitive system parameters that are normally included in the model to compute broadband performance predictions. They are system loss, ambient detection threshold and reverberation detection threshold. The term "unsegmented" frequency sensitive system parameters might seem confusing at first but is intended to signify that valid values of these parameters should be derived for the source pulse as a whole and should not be drawn from the fractional subpulses as was done for the "segmented" system parameters. The appropriate values for these parameters must be determined as they pertain to the entire pulse length and bandwidth of the "unsegmented" source pulse otherwise the signal excess results will be in error.

The reason the methodology for determining the proper values of segmented and unsegmented parameters differs is because of the strategy adopted for the broadband signal excess subroutine in GSM. While the algorithm uses the segmented parameters to compute the magnitudes of reverberation and signal strength for each individual subpulse, the unsegmented parameters are utilized only after all the subband data has been computed and totaled. Both the system loss and the detection thresholds are applied in the signal excess equation to the summed values of reverberation and noise and the averaged values of signal strength. Thus, proper determination of these parameters must reflect the entire bandwidth and pulse length of the undivided broadband source pulse. Proper usage of

both types of parameters in the model should result in reliable signal excess performance predictions for a broadband active sonar system.

REFERENCES

1. H. Weinberg,"Generic Sonar Model," Naval Underwater Systems Center, New London Laboratory, Technical Document 5971D, June 1985.

2. D. Lee and G. A. Leibiger,"Computation of Beam Patterns and Directivity Indices for Three-Dimensional Arrays with Arbitrary Element Spacing," Naval Underwater Systems Center, New London Laboratory, Technical Report No. 4687, February 1974.

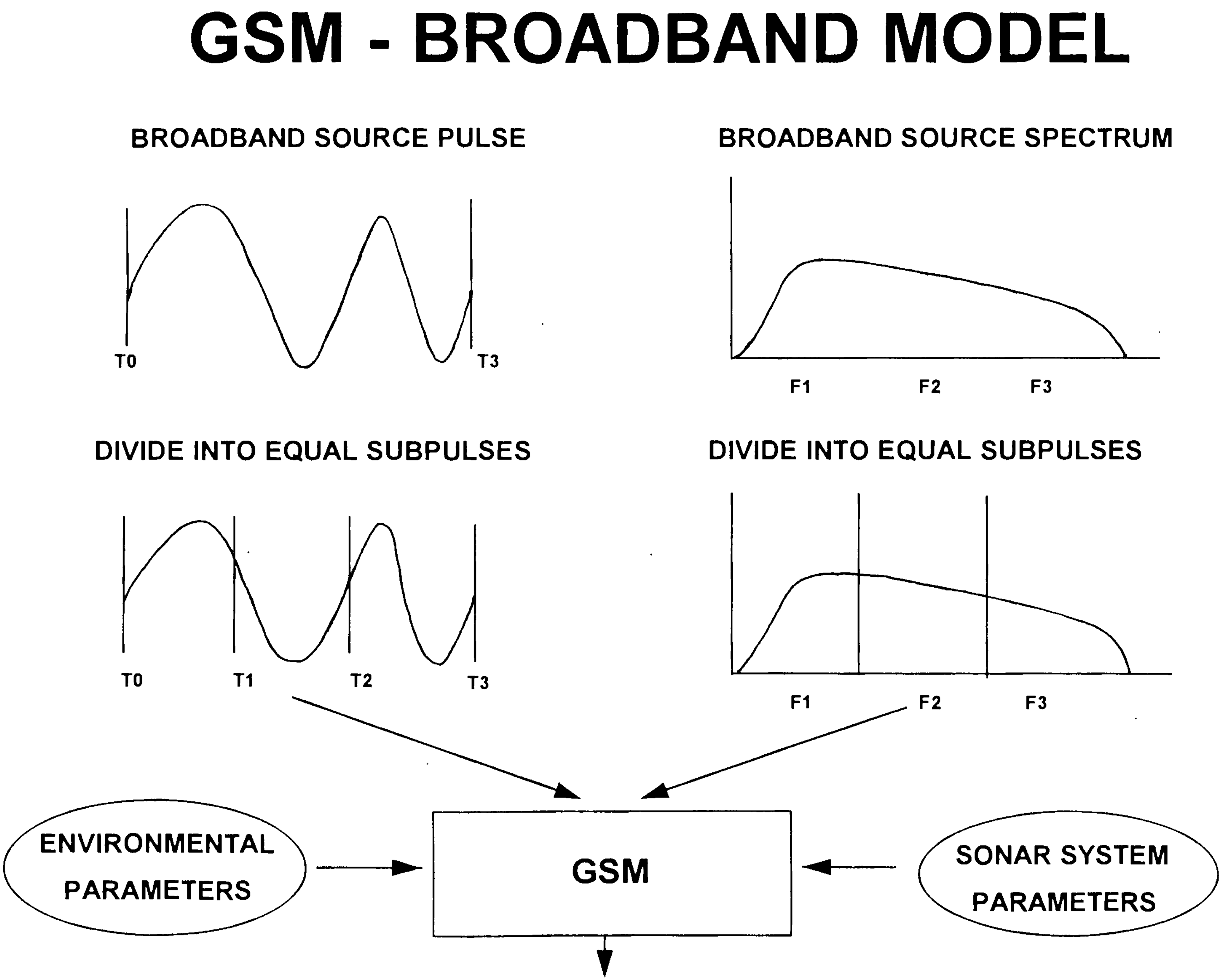

Figure 1: The Broadband GSM Strategy

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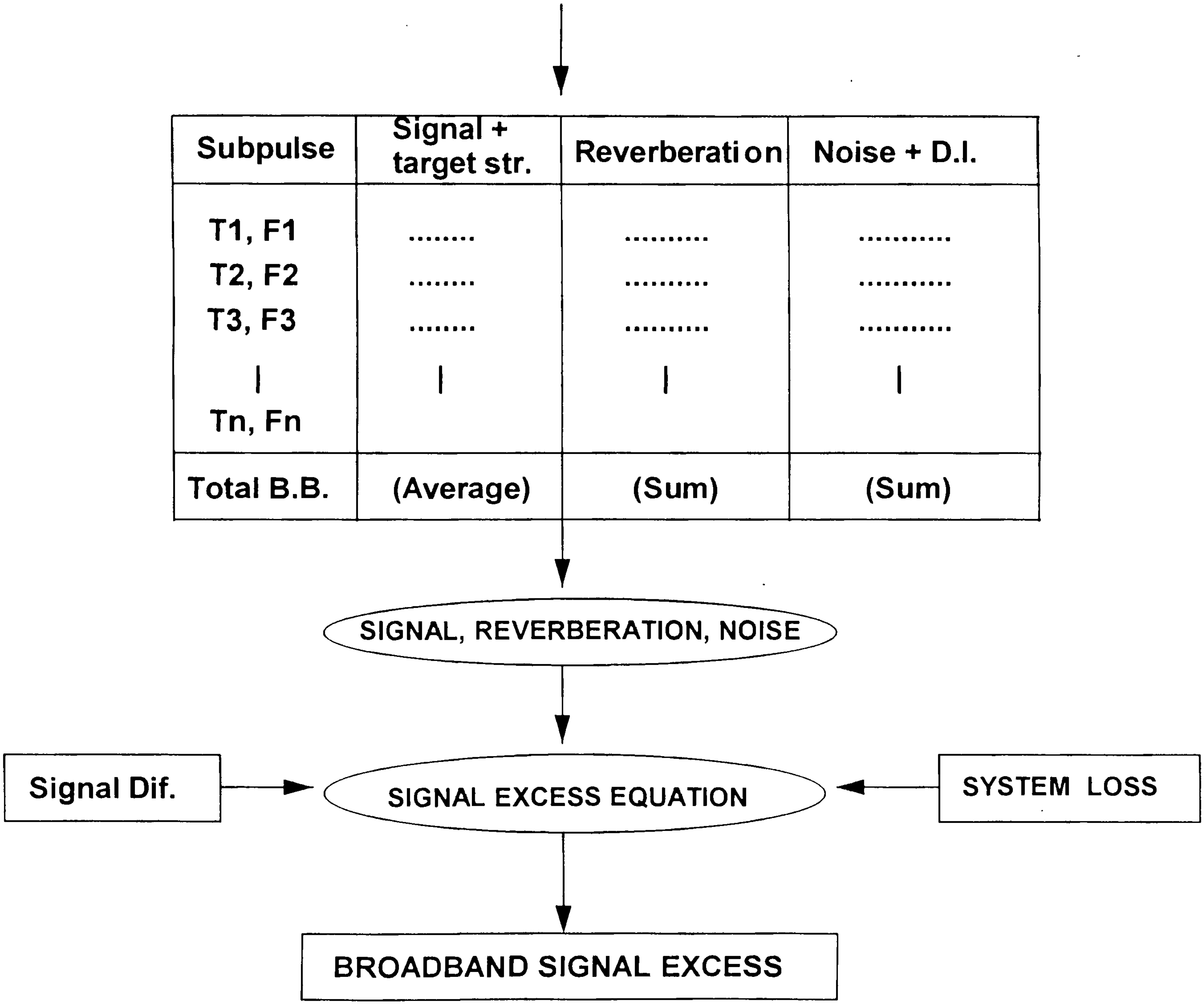

Figure 1 (cont.)

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APPENDIX A : BROADBAND EQUATIONS

SUBPULSE MAGNITUDES

$$\mathrm{M_n = SL_n - TLs_n - TLr_n + TS_n} \qquad \text{(db)} \qquad (1)$$

where:

$M_n =$ Magnitudes of subpulse signal strength (linear)

$SL_n =$ Subpulse source level

$TLs_n =$ Subpulse transmission loss (source - target)

$TLr_n =$ Subpulse transmission loss (target - receiver)

$TS_n =$ Subpulse target strength

PULSE LENGTH WEIGHTED AVERAGE SIGNAL STRENGTH

$$SS = \sum_{n=1...T} M_n \cdot \left(\frac{P_n}{PL}\right) \qquad \text{(linear)} \qquad (2)$$

where:

$SS =$ Pulse length weighted average signal strength

$P_n =$ Subpulse duration

$PL =$ Total pulse length

$T =$ Total number of subpulses

BANDWIDTH WEIGHTED SUBPULSE DOPPLER VELOCITY

$$V_n = (Vs + Vt + Vr) \cdot \frac{W_n}{BW} \qquad \text{(linear)} \qquad (3)$$

where:

$V_n =$ Bandwidth weighted subpulse doppler velocity

$Vs =$ Source component of velocity in direction of sound

$Vt =$ Target component of velocity in direction of sound

$Vr =$ Receiver component of velocity in direction of sound

$W_n =$ Subpulse bandwidth

$BW =$ Total source pulse bandwidth

SUBPULSE BANDWIDTH WEIGHTED DOPPLER SHIFT

$$\Delta D_n = V_n \cdot \left(\frac{F_n}{C}\right) \qquad \text{(linear)} \qquad (4)$$

where:

$\Delta D_n =$ Subpulse bandwidth weighted Doppler shift

$F_n =$ Subpulse center frequency

$C =$ Ocean sound speed

TOTAL REVERBERATION

$$RT = \sum_{n=1..T} R_n \cdot \begin{Bmatrix} 1 - \dfrac{\Delta D_n}{W_n} \\ (0) \end{Bmatrix} \begin{matrix} \text{if } \Delta D_n \le W_n \\ \text{if } \Delta D_n > W_n \end{matrix} \qquad \text{(linear)} \qquad (5)$$

where:

$RT =$ Total reverberation

$W_n =$ Subpulse bandwidth

$R_n =$ Subpulse reverberation

TOTAL AMBIENT NOISE (AND DIRECTIVITY INDEX)

$$NT = \sum_{n=1...T} N_n - DI_n \qquad \text{(linear)} \qquad (6)$$

where:

$NT =$ Total ambient noise

$N_n =$ Subpulse ambient noise

$DI_n =$ Subpulse directivity index

WIDEBAND SIGNAL EXCESS

$$SE = SS - (RT \oplus NT) - LS - DT \qquad \text{(db)} \qquad (7)$$

where:

SE = Wideband signal excess

LS = System loss

DT = Detection threshold

$\oplus$ = Decibel addition

APPENDIX B:

FREQUENCY SENSITIVE PARAMETERS AND MODELS OF GSM VERSION G

1. SEA STATE WIND-SPEED CONVERSION	NAVOCEAN
2. SURFACE REFLECTION COEFFICIENT MODEL	BECHMANN-SPEZZICHINO MARSH-SCHULKIN AMOS
3. BOTTOM REFLECTION COEFFICIENT MODEL MGS	 BLUG FNWC NUC
4. VOLUME ATTENUATION MODEL	FREQUENCY TABLE THORP FISHER-SIMMONS
5. EIGENRAY MODEL	MULTIPATH FAME FACT RAYMODE AMOS
6. TRANSMITTER BEAMPATTERN	FREQUENCY TABLE GBEAM PISTON
7. RECEIVER BEAMPATTERN	FREQUENCY TABLE GBEAM PISTON LINE ARRAY
8. PRESSURE MODEL	DIRECT
9. SOURCE LEVEL MODEL	FREQUENCY TABLE
10. BANDWIDTH TABLE	FREQUENCY TABLE
11. SURFACE SCATTERING STRENGTH	CHAPMAN HARRIS
12. BOTTOM SCATTERING STRENGTH	MACKENZIE
13. VOLUME SCATTERING STRENGTH	FREQUENCY TABLE SAENGER
14. REVERBERATION MODEL	CMPRV5 BISTATIC

15. HORIZONTAL BEAMWIDTH MODEL	FREQUENCY TABLE
16. TARGET STRENGTH	FREQUENCY TABLE
17. AMBIENT NOISE SPECTRA MODEL	FREQUENCY TABLE NUSC WENZ
18. AMBIENT DIRECTIVITY INDEX MODEL	FREQUENCY TABLE
19. SELF NOISE SPECTRA MODEL	FREQUENCY TABLE
20. SELF DIRECTIVITY INDEX MODEL	FREQUENCY TABLE
21. SURFACE SCATTERING SPECTRA MODEL VOLUME SCATTERING SPECTRA MODEL BOTTOM SCATTERING SPECTRA MODEL TARGET SCATTERING SPECTRA MODEL	CONSTANT NORMAL FREQUENCY TABLE
22. DETECTION THRESHOLD MODEL	FREQUENCY TABLE BELL MATCHED FILTER SQUARE WAVE
23. ACTIVE SIGNAL EXCESS MODEL	CMPAX5 (NARROWBAND) CMPAX6 (WIDEBAND)